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DECOMPOSITION AND MOVEMENT OF HERBICIDES IN SOILS, AND EFFECTS ON SOIL MICROBIOLOGICAL ACTIVITY AND SUBSEQUENT CROP GROWTH.

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A THESIS

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UNDER THE DIRECTION OF

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INTRODUCTION

The destruction of weeds by chemical means has necessitated a soil problem. The purpose of this work was, therefore, to investigate the nature of the effect of weed herbicides on the soil.

Sulphuric Acid, Copper Sulphate, Sodium Chlorate and Sodium di-chromate were investigated in relation to their effect on the soil processes and subsequent crops. A preliminary experiment with barium chlorate is also included. The chlorates and chromates act, at least in part, through the soil and results to date have definitely proven that a residual effect soil problem is present.

In the experiments conducted three concentrations of pure chemical were used. These fairly well covered the range used for practical purposes. The concentrations are designated in this paper as check, concentration A, concentration B and concentration C. These will be used throughout the paper. Table I gives the concentrations of the various chemicals used.

In most of the work three types of soil were used; Edmonton Black, a rich black loam high in organic matter; Breton Grey, a typical leached wooded soil; and Winterburn fine sandy loam, a soil of intermediate fertility. Duplicate crocks of

Table I. Rates of applications of chemicals to soil represented by treatments A, B, C, etc.

	Check	A-		A		B		C		C+	
		Gms. per 100 gms.	Lbs. per acre	Gms. per 100 gms.	Lbs. per acre	Gms. per 100 gms.	Lbs. per acre	Gms. per 100 gms.	Lbs. per acre	Gms. per 100 gms.	Lbs. per acre
H_2SO_4	None	----	---	.0024	30	.004	50	.008	100	----	----
$CuSO_4$	"	----	---	.0012	15	.0024	30	.0048	60	----	----
$NaClO_3$	"	----	---	.026	327	.052	654	.104	1308	----	----
$Na_2Cr_2O_7$	"	.013	163	.026	327	.052	654	.104	1308	.146	1883
$Ba(ClO_3)_2$	"	----	---	.039	489	.078	978	.156	1960	----	----

these soils were used in all greenhouse experiments. The field experiments were conducted on plots in Belgravia field by permission of the Field Crops Department, University of Alberta. The plots were of even topography and of typical Edmonton Black soil. The field had been fallowed the year previous to the beginning of the work. All field plots were in quadruplicate. See fig. (1).

With the exception of two experiments all pot work was kept in a greenhouse at optimum moisture and cultivated at regular intervals. Two sets of experiments, one with $NaClO_3$ and one with $Na_2Cr_2O_7$, to note their effect on micro-biological activity, were kept at optimum moisture and maintained at one temperature in a laboratory control chamber.

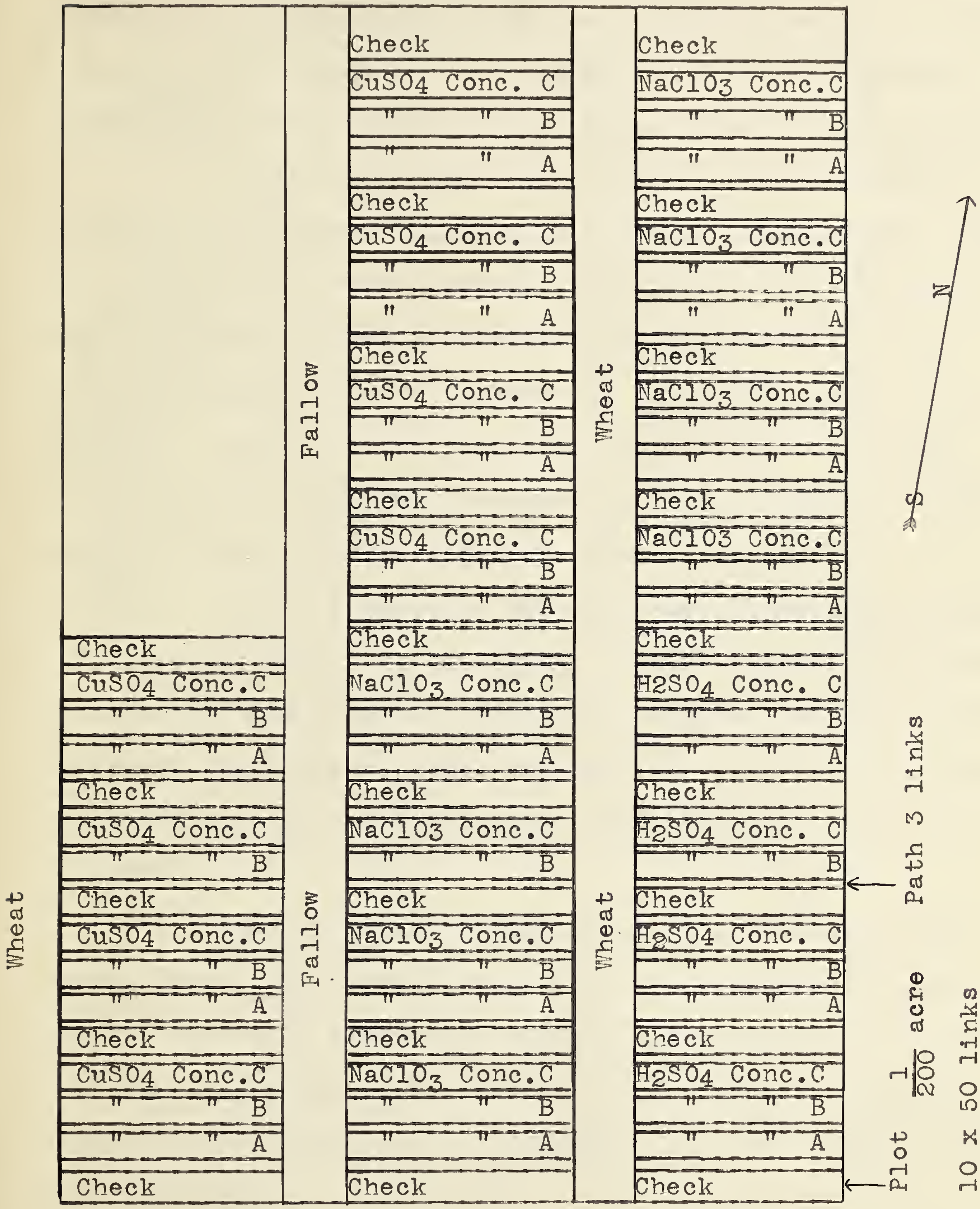
In testing the residual effect on crop growth wheat was the only plant used.

METHODS

Chlorates.

Chlorates were determined by the following method: The soil filtrate was boiled for 15 minutes with standard $FeSO_4$ and the excess titrated with standard $KMnO_4$. This gave quite accurate results. The determination had to be carried out fairly quickly as the organic matter in the filtrate slowly reduced the $KMnO_4$, and consequently reduced the chlorate readings. The first end point reached was the correct one. This method is a modification from Treadwell and Hall (18). It was the only one found satisfactory for such small amounts and applicable to the soil solution.

Fig. 1 -- Plan of Edmonton Field Plot Experiments with H_2SO_4, $NaClO_3$, and $CuSO_4$ in 1931.



By adding flocculents it was found that a higher reading was obtained than by using a soil filtrate to which no precipitating agents had been added. This higher reading is undoubtedly due to less organic matter present in the filtrate.

It was found that soils varied in the amount of chlorate recoverable relative to a stated amount added. With no precipitants added approximately 80% in fine sandy loam, 71% in Edmonton black and 90% in wooded grey soil of the chlorate added could be immediately extracted after one hour of shaking. By adding $CuSO_4$ Carbon Black, $MgCO_3$ and $Ca(OH)_2$, 90% in fine sandy loam, 88% in Edmonton black and 94% in wooded soils, of the chlorate added could be extracted.

Dilute phosphoric acid was added to prevent action of the chloride ion on the $KMnO_4$. Silver nitrate was added to the reduced and unreduced solutions, and the increased opalescence of the reduced samples showed that what was being measured was chlorates and not oxidization products of their decomposition.

The only other method found at all feasible was the $AgNO_3$ method after reduction of the chlorate with ferrous sulphate. But this was unsatisfactory. The amount of chloride was too small to weigh accurately and difficulty in chromate method titration was found due to the reaction of the reagents used in the reduction.

Nitrates

It was found impossible to determine nitrates in the

presence of chlorate by Harper's (8) standard phenoldisulphonic acid method. The chlorate has an effect on the easily oxidized reagent, producing color tints that make an accurate reading impossible.

In most determinations the nitrates were in such minute quantities that titration of nitrates reduced to ammonia was impractical. The only satisfactory method of measuring that could be found was Nesslerization. The difficulty here was to measure accurately the small differences due to the chemical added. Scales' (17) method seemed to be the most satisfactory one to use. The procedure as developed is given below. A clear soil filtrate, .1N with NaOH was reduced with a ZnCu couple. The distillate was treated with Nessler reagent and measured in Nessler tubes. It was found most satisfactory to obtain three different distillates; one where the alkaline solution was immediately reduced and distilled with the metal couple, one where the alkaline solution was boiled and distilled without the metal, and one where the boiled solution was then reduced and distilled with a metal couple. Since it was supposed that the differences found would be small the object was to eliminate as far as possible the error due to free ammonia, ammonia from organic matter and the free reduction of nitrates. Weighing the Nessler precipitate could not be expected to give accurate differences, but could sometimes be used as a check on the color readings. Considerable time was spent in standardizing and applying the above method.

For the determination of nitrates in the presence of chromates the phenoldisulphonic acid method was used. The chromate in the solution was reduced by $FeSO_4$, in the cold. The solution was then made very slightly alkaline and the precipitated iron salts filtered off. The solution could then be evaporated and carried on by Harper's method. Care had to be exercised to prevent loss of nitrates by the vigorous reaction between the phenoldisulphonic acid and the excess of salts present.

Chromates

Chromates were determined by the potassium ferricyanide spot plate method as outlined by Treadwell and Hall (19). The soil filtrate was titrated with standard ferrous sulphate using $K_3Fe(CN)_6$ as an outside indicator.

Microorganisms

The numbers of bacteria and fungi were determined by the plate count method. A nutrient agar medium recommended by Fred and Waksman (5) was used for the bacterial plates, and an acid agar medium recommended by Waksman (6) for the fungi plates.

EXPERIMENTAL RESULTS

Sulphuric Acid

Sulphuric acid is used as a leaf spray, generally for the control of annual weeds. Its lethal action is on the exposed part of the plant. Aslander (3) suggests that H_2SO_4 does not move in the plant and its effect is dependent on the

amount of surface the spray can cover. The applications recommended are from 30 to 100 lbs. per acre. It is seen then that the amount of acid that reaches the soil is necessarily very small. J.D. Newton (15) found in Edmonton Black soil that one ton of sulphur reduced the pH from 6.5 to 5.2 and on Breton grey podsol soil from 6.7 to 5.1. This would suggest that the amount applied in this work would have little or no residual effect on the soil.

Three series of eight one-gallon crocks each of fine sandy loam, Edmonton black and Breton grey soil were set in the greenhouse. Three different rates of application of sulphuric acid were used (see Table I), and all treatments and checks were in duplicate. A series of plots was laid out in the field in quadruplicate (see Fig. 1). These plots were treated with sulphuric acid on July 2nd, 1930. They remained fallow that year and were sown with wheat in 1931.

Nitrates and microorganisms were determined periodically in the plots and crocks in 1930. They are rather irregular but there appeared to be a very slight depression of the nitrates and fungi numbers in the H_2SO_4 treated field plots late in the season. By September 5th the nitrates on the check plots had increased from 30 p.p.m. to 36 p.p.m. while on the plots receiving conc. "C" they had decreased from 28 to 21 p.p.m. However, it appears that there was no important detrimental effect on the soil biological activity as a result of its application.

A crop of wheat sown in the crocks after six months showed no ill effect from the acid treatment. A slight stimulating effect due to the acid was noticeable in the poorer soils;

that is the fine sandy loam and the Breton grey.

The plots were sown with wheat the following spring, in May 1931. No apparent differences were seen in the growing crop. Threshed grain yields on the plots are given in Table II.

No definite trend is noted and the differences in yield are not really significant.

Copper Sulphate

As a result of the comparative success of $CuSO_4$ as a chemical for the destruction of annual weeds it was decided in 1931 to test its residual effect. With $CuSO_4$, as with H_2SO_4, it was felt that the amount added was too small to have any detrimental residual effect on the soil. Bourcart (4) says: "The soil is capable of absorbing enormous quantities of $CuSO_4$ without the latter injuring the plant". He also suggests that this is due to the formation of the more insoluble and less toxic copper salts by reaction with the soil. This is emphasized by Marshall (13) who points out that with metallic salts the toxic action will depend mainly on the metal in solution. A series of 24 crocks similar to that used for the sulphuric acid treatment was outlined. The treatments were as stated in Table I. The crocks were maintained in the greenhouse at optimum moisture and cultivated every two weeks.

Nitrates were determined monthly for four months by the phenoldisulphonic acid method. (See Table III). Although no definite trend can be noted it appears as if there was some stimulation in the richer soils due to the copper sulphate. This

Table II. Wheat yields of Edmonton Field Plots 1931.
Straw in tons per acre
Wheat in bus. per acre

Treatment		Date of application July, 1930 H_2SO_4	June, 1931 $CuSO_4$	July, 1930 $NaClO_3$
Ch.	Straw	3.95	4.06	3.88
	Grain	55.3	51.9	50.1
	%grain	33.8	31.2	31.8
A	Straw	3.63	4.29	.88
	Grain	50.5	57.3	7.3
	% grain	33.7	33.1	19.3
B	Straw	3.37	4.04	.51
	Grain	45.3	56.9	1.7
	% grain	32.8	34.3	7.8
C	Straw	3.55	3.70	.17
	Grain	50.5	52.3	.02
	% grain	34.6	34.7	1.2

The H_2SO_4 applied in 1930 and the $CuSO_4$ applied in 1931 had little effect on the 1931 wheat yields, but the $NaClO_3$ applied in 1930 had a very great effect on 1931 wheat yields.

See Table I for rates of application represented by Treatments A, B, and C. Each yield figure represents an average of four plots.

Table III. Nitrates (p.p.m.) in pot cultures treated with $CuSO_4$ 1931

	March 3	May 9	June 6	June 30	Aug.14
Wooded Ch.	Trace	36	31	27	40
" A	"	32	46	29	36
" B	"	33	35.5	27	24
" C	"	35	26	37	23.5
Fine Sandy Loam					
Ch.	7.2	44	64	57	36
" A	"	48.5	70	39	73
" B	"	42	100	44	57
" C	"	38	35	40	133
E. Black					
Ch.	24	50	70	99	182
" A	"	61.5	80	100	160
" B	"	70	94	88	159
" C	"	52	67	100	133

The nitrates show no definite trend following the application of $CuSO_4$.

stimulation lasted only a short time after application. It also appears as if the weakest concentration stimulated sooner than the next higher concentration. Greaves'(7) work on the effect of salts on soil microorganisms shows that a stimulation can be expected in weaker concentrations of a toxic salt. This is what appears to have happened with the addition of $CuSO_4$ in small amounts.

Six months after treatment with the sulphate the crocks were sown with wheat. No difference was noted in germination or in subsequent growth.

On June 26th, $CuSO_4$ was applied to a series of plots of growing wheat. There was a heavy rain twelve hours after application. Two days later considerable burning of the wheat leaves was observed. The plots receiving sixty pounds per acre appeared quite brown. As the wheat neared maturity the check plots lodged badly, while those receiving sulphate remained upright. The yields of wheat on these plots are given in Table II.

These figures show a small but definite increase in the ratio of grain to straw with the application of $CuSO_4$. A stimulation due to concentration "A" and a depression due to concentration "C" might also be noted. However, neither one of these is significant. If the check plots had not lodged they would, probably, have given a significantly higher yield than the treated plots.

A series of fallow plots was treated on June 26th, 1931. The $CuSO_4$ had a lethal effect on the growing weeds at the time

of application. However, it did not have any apparent residual effect on any growth appearing after its application.

Sodium Chlorate

Chlorates are used mainly for the eradication of perennial weeds because their toxic action appears to persist over a much greater period of time than the leaf sprays, and therefore present the greatest residual effect problem. Sodium chlorate was used as the type example and the major part of this work was devoted to its study.

The experiments conducted have shown that sodium chlorate affects certain normal soil processes to a limited extent. It has not been possible, however, from this investigation to explain why it acts thus.

Up to the present there is no definite data as to the cause of toxic action of chlorates.# Neller (16) says it is possible that the slower action and the higher toxicity of $NaClO_3$ is due to the gradual decomposition within the plant tissues accompanied by the liberation of nacent oxygen. Also that the chlorates lower the catalyse activity of the roots. Loomis, Bissey and Smith (12) believe that the herbicidal action consists of both direct killing of underground portions of the plant and of a translocation to and slow killing of new sprouts. Latshaw

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We have been unable to find any published article that deals directly with the effect of the oxidizing chemicals on the soil.

and Zahnley (11) suggest that it interferes with photosynthesis and compels the plant to draw upon the root reserves until they are exhausted and die. However, Loomis, Bissey and Smith (12) say its action can go on in the absence of ultra violet light. Although our results show that the chlorate has a definite effect on micro-biological processes in the soil it appears quite evident that its toxic action is not from that source. Loomis, Bissey and Smith (12) and Aslander (2) suggest that the chlorate is more effective if applied to the soil. It seemed reasonable therefore, to suggest that a study of its effect on the soil and its movement in the soil is important.

A series of plots in quadruplicate was laid out in the spring of 1930. These were treated July 28th, 1930, with sodium chlorate according to Table I. Bacteria and fungi determinations were made at intervals during the year. The numbers are rather irregular and show no definite trend following the application of chlorates. Nitrates were not determined that summer as no satisfactory method of determining nitrates in the presence of chlorates was at that time standardized.

In the spring of 1931 the plots were sown with wheat. Chlorate damage was noticed with the first appearance of the shoots. The plots receiving the heaviest application were practically barren. What few seeds germinated or appeared above the surface survived only a short time. Any growth supported by these plots, conc. "C", germinated almost a month later. Plate I, Fig. 2 shows the appearance of the plots shortly before harvest. The yields of wheat are given in Table II and indicate

PLATE I

Fig. 2. Wheat on field plots the year following treatment with sodium chlorate.

Fig. 3. Growth of wheat on soil maintained under greenhouse conditions six months after application of sodium chlorate.

the graded or corresponding effects of the different concentrations applied. All applications of chlorates materially reduced the yield. The plot receiving concentration "A", 327 lbs. per acre, gave a yield of 7 bu. per acre as against a 50 bu. yield on the check plot. Concentration "B" and Concentration "C" reduced the yield to practically nothing. Concentration "B", 654 lbs. per acre, approximates the average application recommended for the control of perennial weeds. It appears that under climatic conditions such as prevailed in 1930, Edmonton black soil, treated with 600 lbs. of $NaClO_3$ per acre, will remain sterile to wheat for at least one year. 1930 was a relatively dry season with a long open dry fall. Although no analyses were made it may be supposed that in the spring of 1931 the chlorate was still concentrated quite close to the surface. It was, therefore, quite toxic to the young plants. These results are similar to the findings of Arny, Bridgford and Dunham (1). They state that when from 600 to 800 lbs. per acre were applied the soil often remained sterile for a year. Megee and Lipscomb (14) state that the residual effect of a spring application usually disappeared by September. The length of time that chlorates will remain in the soil, toxic to the plant, seems to be a point upon which many different opinions are expressed. The investigations indicate that although the fertility of the soil and its percentage of organic matter are factors, rainfall and leaching are more important because they affect its distribution in the soil and therefore its toxicity to the plant.

On August 18th, 1931, the upper three feet of soil

were sampled and analysed for chlorate content, each foot separately. It was found that most of what still remained undecomposed was concentrated in the third foot (see Table IV). 1931 was a season of high rainfall. This possibly explains why growth starting on the plots later in the season appeared almost normal. The question raised by these analyses is whether the chlorate will decompose as rapidly in the subsoil. Also, whether excessive evaporation later will bring it back close to the surface.

Loomis, Bissey and Smith (12) state that chlorates will leach in the soil and that under moist conditions become concentrated in the lower levels of the soil. This they say is next only to temperature in importance. Our investigations suggest that ordinary temperatures have little effect on its decomposition. Green house temperature for 18 months has failed to completely decompose it in the soil. The following experiment suggests that the chlorate does not enter into chemical union with the soil, and that once leached out, the soil returns to its normal productive power.

On October 27th, 1931, samples of the upper three feet were again taken (and analysed for chlorate content). Portions of these samples were placed in tumblers in the greenhouse and seeded to wheat. Growth relations at the end of five weeks are given in Table V. This experiment indicates that the chlorate can be leached out beyond the limit of its toxic concentration and that a normal growth can be subsequently supported. It suggests two possibilities: First, that field results for

Table IV. Penetration of $NaClO_3$ in the Edmonton soil under field conditions.

Determination made August 18th, 1931.

	Applied July 1930		Applied June 1931		Amount added per plot
	Gms. per plot	Total per plot	Gms. per plot	Total per plot	
Check 0' to 1'	0.0		0.0		
" 1' to 2'	0.0		0.0		
" 2' to 3'	0.02		0.02		
		.02		.02	none
Conc. A. 0' to 1'	0.0		0.0		
" 1' to 2'	123.0		82.0		
" 2' to 3'	240.0		369.0		
		363.0		451.0	742.0
Conc. B. 0' to 1'	0.0		0.0		
" 1' to 2'	123.0		246.0		
" 2' to 3'	410.0		492.0		
		533.0		738.0	1483.0
Conc. C. 0' to 1'	123.0		164.0		
" 1' to 2'	410.0		574.0		
" 2' to 3'	574		738.0		
		1107.0		1476.0	2966.0

These determinations indicate that the $NaClO_3$ tends to leach down into the subsoil in a moist season.

Table V. Crop (5 weeks growth) on field samples taken October 27th, 1931, from Edmonton plots previously treated with sodium chlorate

Treated July		0-1 foot	1-2 feet	2-3 feet
	Ch.	Normal growth	Normal growth	Normal growth
	A	Normal growth	Normal growth	Normal growth
1930	B	Normal growth	Normal growth	Some whitening
	C	Normal growth	Some whitening, $\frac{3}{4}$ crop	Some whitening and retardation, $\frac{1}{2}$ crop
	Ch.	Normal growth	Normal growth	Normal growth
	A	Normal growth	Some retardation, $\frac{3}{4}$ crop	Some retardation, $\frac{3}{4}$ crop
1931	B	Normal growth	Some whitening, $\frac{3}{4}$ crop	Some retardation and whitening of leaves, 2/3 crop
	C	Some leaves dead, $\frac{3}{4}$ crop	Some whitening and retarding of crop, $\frac{1}{2}$ crop	Whitened and retarded, 1/3 crop

These results indicate that the sodium chlorate will leach down into the subsoil in a moist season. A normal growth is supported once the chlorate is leached out.

next year will be quite different from this year's results; and, secondly, the possibility of growing a shallow rooted crop the season following the application of chlorate, with reasonable success. Halbert, Remsbey and Spence (10) state that cultivating the treated soil before the following spring renders the chlorate less effective. This, I believe, is related to the leaching factor. The surface soil can be leached of its chlorate beyond the limit of its toxic concentration. Cultivation would therefore permit the upper broken portions of the roots to produce a healthy plant away from the action of the chemical.

A series of three soils was placed in the greenhouse in 1930 and treated with $NaClO_3$ at the rates stated in Table I. The soils and the arrangement of crocks were the same as in the case of the H_2SO_4 experiment previously discussed. The soils were maintained at optimum moisture and cultivated every two weeks. Fungi and bacteria counts showed no definite trend. This was partially due to the fact that neither the temperature nor humidity could be controlled. An experiment discussed later, conducted in a controlled chamber, gave more significant results. At the end of six months the crocks were sown with wheat. The appearance of the crop is seen from Plate I, fig. 3. The heaviest concentration on the Breton grey soil practically prevented any growth whatever. Crops sown at nine and twelve months showed a slight but steady improvement, especially in the Edmonton black soil. At the end of twelve months all the black soil crocks were practically back to normal excepting the "C" concentration which showed about a two-third's crop. At the end of the

twelve month's period the "C" concentration on the Breton grey still gave a 100% retardation of growth.

Table VI gives the amounts of chlorates remaining in the soil. It shows that decomposition is taking place very slowly in the two poorer soils, and that in the richer black soil under greenhouse conditions it will take at least a year for 650 pounds per acre to decompose.

One year after the application of the chlorate one of each of the duplicates of this series was leached with six inches of tap water. The amounts of sodium chlorate obtained by this leaching are given in Table VII. The results indicate that it is possible to leach most of the chlorate out, but that it is more difficult to leach it out of the richer soils.

One month after these crocks were leached they were planted with wheat. As compared with the unleached crocks of the series, the leaching had removed much of the toxic element. However, the leached crocks all show some chlorate damage. In three weeks conc. "C" wooded leached had a crop 3 inches high, whereas the wheat on the unleached did not appear through the surface. (See Plate 2, fig. 4).

There was practically no difference between conc. "C" black soil leached and unleached. It was thought that possibly the chlorate might have left a toxic oxidization product in the soil of high organic matter content, but later experiments seem to disprove this. As suggested before, the chlorate is harder to leach out or extract from the richer soils. This suggests that chlorates remain relatively free in the soil and that they can be moved about in the soil by soil water.

Table VI. $NaClO_3$ decomposition in pot cultures
Grams of $NaClO_3$ per 100 gms. of soil

Soil	Series II	Series I	
	August, 1931	September, 1931	December, 1931
Black Ch.	----	----	----
" A	.005	.001	----
" B	.029	.019	.011
" C	.080	.049	.051
F.S.L. Ch.	----	----	----
" A	.005	.004	.006
" B	.031	.010	.012
" C	.050	.051	.040
Wooded Ch.	----	----	----
" A	.016	.008	.011
" B	.042	.020	.027
" C	.086	.046	.036

Series I was started in July 1930 in the greenhouse and maintained at optimum moisture throughout.

Series II was started in November 1930. It was left outside frozen till spring and then placed under greenhouse conditions in May 1931.

This table shows the more rapid decomposition of $NaClO_3$ under greenhouse conditions.

Table VII. Leaching of crocks one year after treatment with $NaClO_3$. Figures represent grams of $NaClO_3$ per 3000 grams soil.

	First 2" leachings	Second 2" leachings	Third 2" leachings	Total 6" from 3000 gms.	Amount remaining after leaching	Amount decomposed in 1 year	Amount Applied
Wooded grey							
Wooded Ch.	.013	.006	.004	.023	.013	-.039	0.0
" A	.469	.064	.022	.555	.053	.211	.78
" B	.865	.186	.103	1.154	.079	.366	1.56
" C	2.165	.386	.144	2.695	.106	.368	3.13
Fine Sandy Loam							
" Ch.	.009	.007	.006	.022	.053	-.075	0.0
" A	.525	.041	.034	.600	.053	.202	.78
" B	.609	.148	.093	.850	.095	.690	1.56
" C	1.000	.428	.137	1.565	.095	1.545	3.13
Edmonton Black							
" Ch.	.009	.003	.003	.015	.039	-.054	0.0
" A	.463	.012	.007	.482	.039	.310	.78
" B	.542	.100	.048	.690	.119	.722	1.56
" C	1.173	.327	.180	1.680	.265	1.236	3.13

The results indicate that it is possible to leach most of the chlorate out of soils, but that it is more difficult to leach it out of the richer soils. The quantities in the check samples represent the error of the determination, and allowance is made for this error in the column of amounts decomposed in 1 year.

PLATE II

Fig. 4. The effect of leaching soil one year after treatment with sodium chlorate. Tumblers marked "L" were leached with six inches of water.

Fig. 5. The neutralizing effect of ground alfalfa added to sodium chlorate treated soil. Wheat was sown ten weeks after the chemical was applied

A series of twenty-four crocks treated with chlorate was started November 10th, 1930, and left outside, buried at ground level all winter. The frost did not appear to have any beneficial effect in aiding decomposition. Amounts of chlorate in this series are given in Table VI.

An experiment was outlined to test the neutralizing effect, if any, on chlorate, of farmyard manure, sulphuric acid and sulphur. Sixteen crocks of fine sandy loam were placed in the greenhouse. There were four each of (1) manure, twenty-five tons per acre; (2) sulphur, one ton per acre; (3) sulphuric acid, one ton per acre; and (4) four check crocks. Two crocks of each set were treated with sodium chlorate at the rate of 654 pounds per acre. They were kept fallow for six months. At the end of this time a crop of wheat was planted. In general none of these satisfactorily neutralized the toxic effect of the chlorate. All chlorate treated crocks showed much damage. There was no advantage whatever noted for the sulphur over the check. The sulphuric acid appeared slightly better than the check. The manure treated crocks supported a growth twice as great as that of the check crock, but it was badly whitened and of a spindly nature.

Amounts of chlorates were determined after the crop was removed. Very little difference was noted in the results, although slightly more had decomposed under manure than in the other three, namely, sulphur, sulphuric acid and check crocks.

The above experiment suggested that if sufficient organic matter were added to the soil the effect of the chlorate could be neutralized. Further, that if an excess of easily de-

composed alfalfa were added to the soil more definite information could be obtained as to the effect of sodium chlorate on nitrates and nitrification processes.

Three series of four jars each were prepared and treated with chlorate, at the same rates as in previous experiments. Series I was fine sandy loam alone, series II was fine sandy loam plus 5 per cent alfalfa, and series III was fine sandy loam plus ten per cent alfalfa. Two weeks after application of the chlorate excessive decomposition was noted in series III. The extent of decomposition was proportional to the chlorate added.

Analyses for chlorate are given in Table VIII. Where 10 per cent alfalfa was added practically all the chlorate was decomposed within 4 weeks. In 6 weeks wheat was sown on a portion taken from each jar. Series I showed the expected harm from the chlorate. Series II showed a little effect of the chlorate and concentration "C" supported about one half a crop. In series III a normal healthy crop grew on all four jars. There was no evidence of any residual effect from any of the concentrations. This suggests two conclusions: First, that it is possible to add enough organic matter to decompose the chlorate, and secondly, that when it has decomposed it does not leave any lethal oxidation products, and that the lethal substance is definitely the chlorate itself. (See Plate 2, fig. 5). This does not bear out Harper's (9) conclusion that chlorates disappear quickly from the soil in a warm moist climate and that their toxic effect is due to the depression of nitrating power or the residual oxidation products of their decomposition.

Table VIII. Decomposition of sodium chlorate with excess organic matter in soil pot cultures. $NaClO_3$ in gms. per 100 gms. soil.

		Added	4 weeks	6 weeks	8 weeks	10 weeks	14 weeks
	Ch.	None	----	----	----	----	----
Series I	A	.026	.026	.014	.025	.019	,002
Fine sandy loam	B	.052	.037	.028	.037	.034	.033
	C	.104	.097	.083	.075	.080	.078
	Ch.	None	----	----	----	----	----
Series II	A	.026	.021	.012	.013	.011	.008
F.S.L+ 5% alfalfa	B	.052	.037	.032	.023	.024	.031
	C	.104	.086	.067	.075	.070	.081
	Ch.	None	----	----	----	----	----
Series III	A	.026	.011	.010	----	----	----
F.S.L. +10% Alfalfa	B	.052	.012	.011	.010	----	----
	C	.104	.006	.003	.009	.005	----

These results indicate that $NaClO_3$ will decompose quite rapidly in a moist well aerated soil, in the presence of 10% readily decomposable organic matter.

Nitrates were determined on the three series at intervals. Results are given in Table IX.

On fine sandy loam without the addition of alfalfa, there was, if anything, a stimulation of nitrification up to six weeks due to the chlorate application. By eight weeks that difference was levelling out and by ten weeks a noticeable retarding of nitrate accumulation is noted. In series II with 5 per cent alfalfa added a reverse effect is noted. After four weeks there was a rapid increase in direct proportion to the chlorate added. This series is significant as showing that nitrification will proceed in the presence of chlorate, because the chlorate had not decomposed. The depression of nitrates at four weeks in series III is due to the excessive decomposition at that time. At this point practically all the chlorate had decomposed and nitrification progressed rapidly after that date. Plate 3, fig. 6, shows the progress of nitrification under concentration "C" of each series.

To obtain more accurate information regarding the effect of chlorate on the micro-flora of the soil four series were placed in the control chamber at 27° C. The soil used was fine sandy loam, and each series consisted of a control and the A, B, and C applications of sodium chlorate. One series was removed for analyses every two weeks.

The amount of chlorate still obtainable in the soil at each analysis showed that although a little decomposition took place the greater part remained at the end of the two months. (See Table X).

There was a definite depression of fungi numbers as

Table IX. Nitrate nitrogen (p.p.m.) in fine sandy loam pot cultures treated with chlorate and alfalfa Sept. 3, 1931.

		2 weeks	4 weeks	6 weeks	8 weeks	10 weeks	14 weeks
Series I	Ch.	12	15	10	13	62	41
	A	12	15	10	22	45	8
	B	12	9	30	20	19	8
	C	14	18	40	23	10	11
Series II 5% alfalfa added	Ch.	25	45	50	80	51	72
	A	30	33	53	95	85	27
	B	27	30	110	210	146	72
	C	25	27	70	165	313	90
Series III 10% alfalfa added	Ch.	35	60	85	100	400	400
	A	36	15	75	146	311	200
	B	38	14	37	180	420	320
	C	40	12	32	130	473	300

Series I indicates a small increase due to $NaClO_3$ followed by a similar depression

Series II indicates that rapid nitrification of organic matter will occur in the presence of $NaClO_3$, as much of the $NaClO_3$ remained undecomposed at 10 weeks.

In Series III practically all of the $NaClO_3$ was decomposed at 4 weeks.

PLATE III

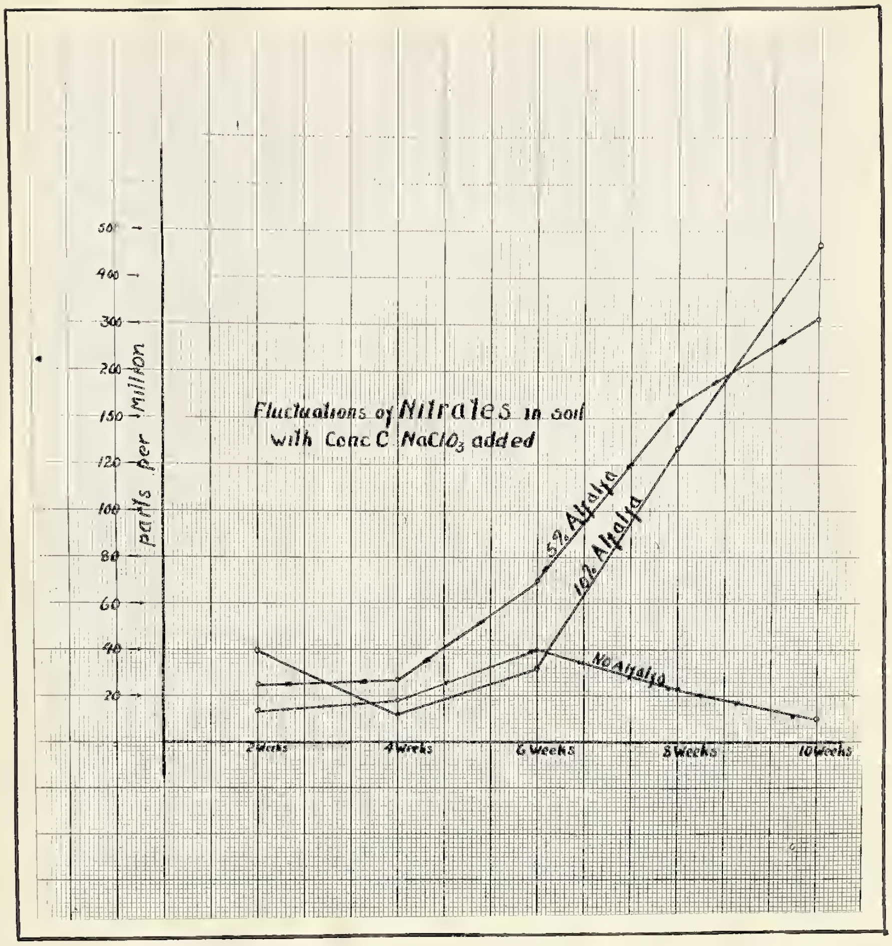


Fig. 6. This graph shows that nitrification will proceed in the presence of sodium chlorate under greenhouse conditions. With ground alfalfa added the nitrates increased.

Table X. Decomposition of $NaClO_3$ on a controlled laboratory experiment using fine sandy loam. Temperature $28^{o}C$.

Applied May 5	May 19	June 1	June 16	June 18
None	.005	.006	.004	.002
.026	.0185	.018	.019	.016
.052	.043	.039	.039	.031
.104	.074	.076	.075	.060

Multiplying quantities in the last four columns by 5/4 will give approximate $NaClO_3$ left in the soil at each determination.

shown by the plate count method. Their numbers show a gradual decline following the initial stimulation. This stimulation was probably due, at least in part, to the more ideal conditions of the experiment. The counts at the end of the first two weeks show a depression in numbers relative to the concentration applied, the higher the concentration of chlorate, the lower the numbers.

The total or bacterial counts were less regular than the fungi counts but showed a definite decrease for the entire two months as a result of the sodium chlorate applications. Plate 4, fig. 7 shows the above results graphically.

This experiment suggests that the application of $NaClO_3$ has a depressing effect on the micro-flora of the soil when readily decomposable organic matter is not also added to the soil. It is known that various chemical compounds have a decided effect on the behavior of micro-organisms. Such factors as flocculation, pleomorphism and the selective action of the media must be considered. No attempt was made to secure any data beyond the numbers as shown by the plate count. However, it is fully realized that this depression may be only apparent and that the results obtained may be due to factors other than a decrease in actual numbers.

Chemical weed killers have been quite extensively used in the irrigation districts of this province. In cooperation with the Field Crops Branch of the Provincial Department of Agriculture, samples were obtained from chlorate treated plots at Brooks, Alberta.

As these plots had been subjected to both irrigation

PLATE IV

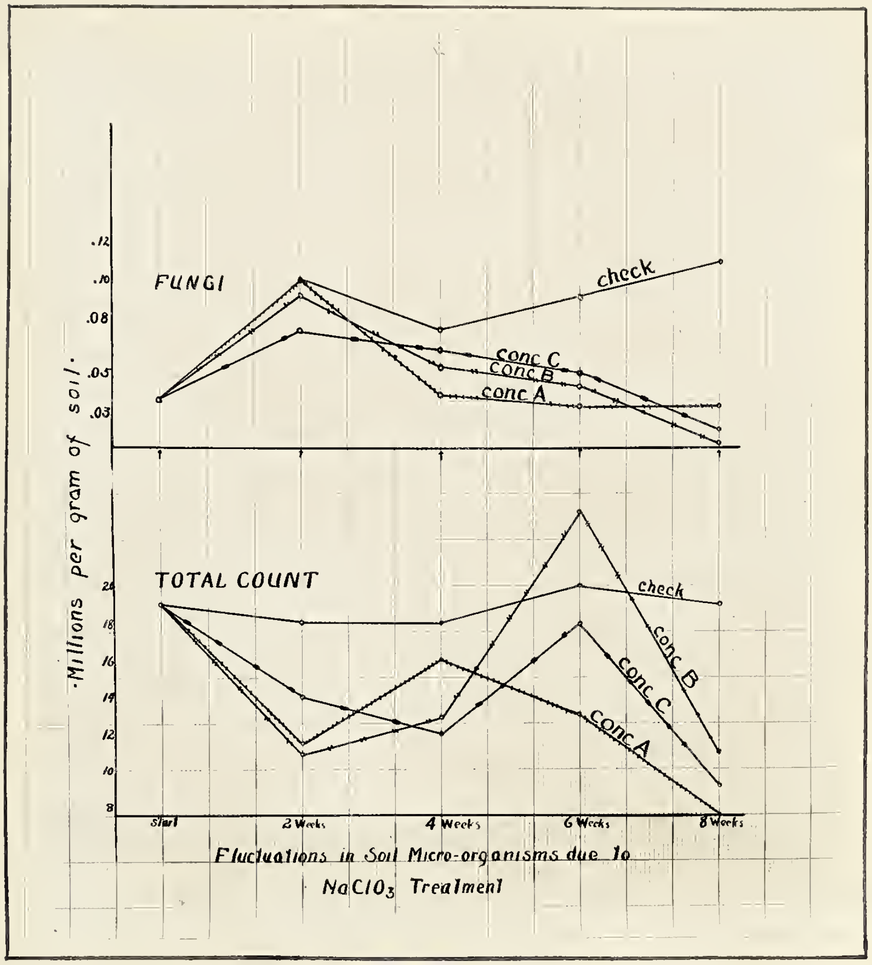


Fig. 7. This graph shows that under controlled conditions sodium chlorate depressed the numbers of soil microorganisms.

and seepage and since the chlorate was applied to the standing crop the chlorate analyses were very irregular. However, one or two things seem pertinent. The chlorate follows the water table fairly consistently. In the seeped plots it is concentrated near the surface; in the irrigated plots it is concentrated down two or three feet. Plots receiving two irrigations after the chlorate treatment had the chlorate concentrated in the first and second foot. Those receiving three irrigations showed the highest concentrations in the second and third foot.

It is difficult to say if the chlorate carried down will decompose or if it will be carried back to the surface. It does seem reasonable to suggest that under ordinary irrigation practice shallow feeding plants might be grown the year following the application of the chemical, with reasonable success.

Sodium di-chromate

As sodium di-chromate was proving a successful herbicide it was decided to include it in our list.

As a preliminary experiment, eight crocks of Edmonton black soil were treated in duplicate. The concentrations were similar in percentage to the chlorate concentrations used in previous experiments. At the end of four months these crocks were sown with wheat. At the end of one month no difference in growth whatever was seen in any of the crocks. That is, there was no residual lethal effect due to chromate. Determinations at the end of the five months showed that the chromate had all

decomposed.

As a result of the above preliminary experiment a series of tumblers containing fine sandy loam soil was placed in a control chamber. The series was increased from four to six. The concentrations used are given in Table I. A wider range was thought desirable because at present there is no definite knowledge as to its lethal concentration. The heaviest application also gives an oxidation equivalent to concentration "B" of sodium chlorate.

One series was removed every two weeks. Fungi and bacteria numbers were obtained and nitrates determined. The amount of Cr_2O_7 decomposition and the effect on a growing crop were also noted every two weeks. The effect on a growing crop was determined by planting and observing growth of wheat in small dishes of the incubated soil.

The $Na_2Cr_2O_7$ experiment has given some significant results. Excepting in concentration "A" the sodium di-chromate had a depressing effect on nitrates and nitrification. See Plate 5, fig. 8. The heavier applications reduced the nitrates to a very low amount. Concentration "A" acted as a stimulant and has slightly increased the accumulation of nitrates over the check. (See Table XI).

The di-chromate appeared to decompose under controlled conditions quite rapidly. By the end of the eight week period only a trace could be recovered from the soil receiving the heaviest concentration, namely C+. (See Table XI).

$Na_2Cr_2O_7$ reduced the number of fungi for the period

PLATE V

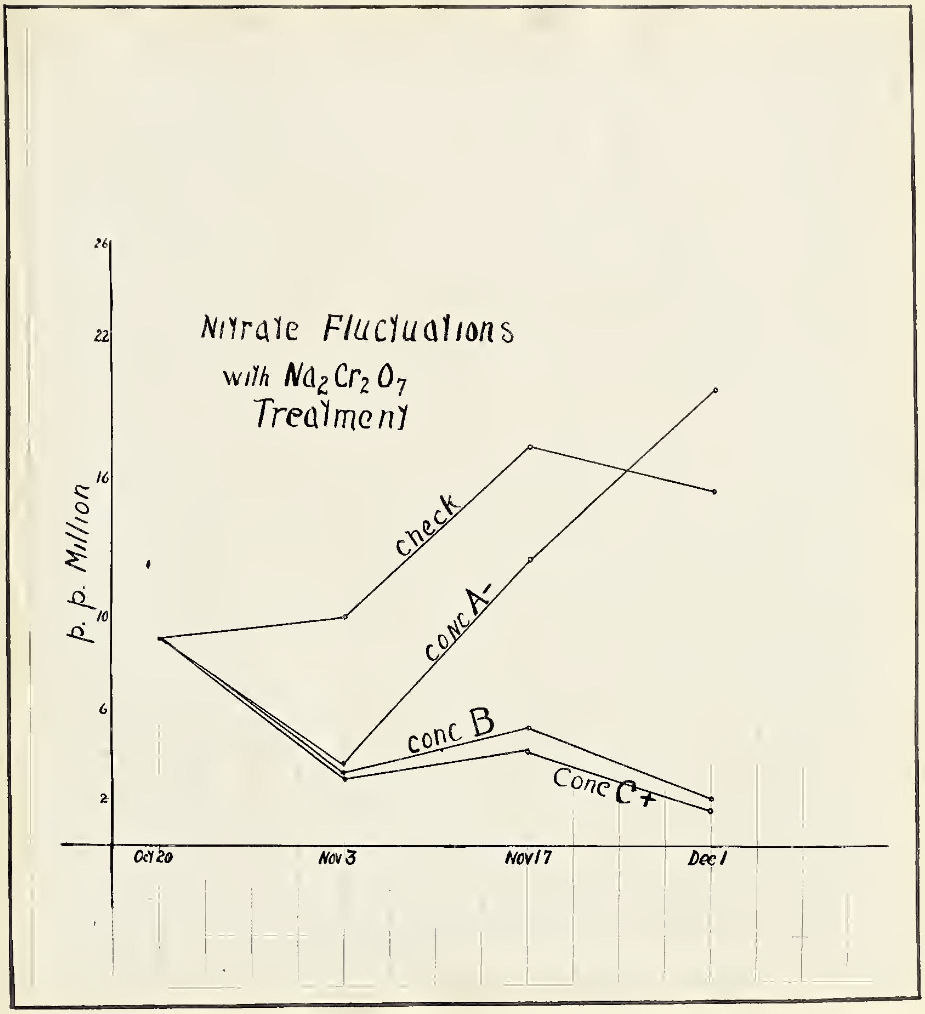


Fig. 8. This graph shows the depressing effect of sodium di-chromate on nitrification. Determinations were made on fine sandy loam maintained under controlled conditions.

Table XI. Amounts of $Na_2Cr_2O_7$ in fine sandy loam tumblers

	At start	2 weeks	4 weeks	6 weeks	8 weeks
Conc. Ch.	.0	.0	.0	.0	.0
" A-	.013	.0	.0	.0	.0
" A	.026	.011	.005	.007	.0
" B	.052	.021	.011	.010	.006
" C	.104	.064	.048	.025	.006
" C+	.146	.117	.086	.030	.012
Amounts of nitrates in p.p.m. in $Na_2Cr_2O_7$ treated fine sandy loam tumblers.					
Conc. Ch.	9	10	17.5	15.4	15.0
" A-	9	3.5	12.5	20.0	25.0
" A	9	3.0	5.1	3.0	1.5
" B	9	3.1	5.1	2.0	1.0
" C	9	5.0	4.4	1.6	2.0
" C+	9	3.0	4.2	1.6	1.2

These determinations indicate that $Na_2Cr_2O_7$ decomposes fairly rapidly in common soil, and that nitrification is greatly retarded in its presence.

of eight weeks. Its action, however, on the total count appears to be selective. With increasing concentrations of chromate there is a relative decrease in the main type of colony found in the check, but an increase in a typical pin point colony. In the soil receiving the higher concentrations it became very abundant, reaching the extent of over one hundred million per gram. (See Table XII).

The growth of wheat every two weeks is shown in Plate 6. A distinct retardation relative to the sodium dichromate was noted at first. However, later sets showed that this toxicity is not persistent and became less apparent. The retarded plants on the soil receiving the higher concentrations did not show the characteristic whitening of chlorate poisoning. Apart from their diminutive growth they appeared quite normal. This retardation persisted after the chromate appeared to have decomposed. This suggested that the effect may be due to factors other than oxidation.

A series of fine sandy loam tumblers, check and concentration "C", was allowed to incubate in the control chamber for three weeks. At the end of this period they were removed and planted with wheat. One set of conc. "C" was treated with KNO_3 at the rate of 75 p.p.m. of nitrogen as nitrate nitrogen; a similar set was treated with nutrient solution at an equivalent rate with respect to nitrate nitrogen. It was thought that the depression of nitrates might have been partially responsible for the dwarfish growth supported by the chromate treated soil. Neither the nutrient solution nor the nitrate application appeared to neutralize the effect of the sodium di-chromate.

Table XII. Fungi numbers in $Na_2Cr_2O_7$ treated fine sandy loam tumblers.

	At start	2 weeks	4 weeks	6 weeks	8 weeks
Conc. Ch.	12	24	30	24	24
" A-	12	15	20	23	20
" A	12	11	24	19	24
" B	12	18	21	27	23
" C	12	16	11	19	13
" C+	12	5	9	13	19
Times 1000 = number per gram of soil					

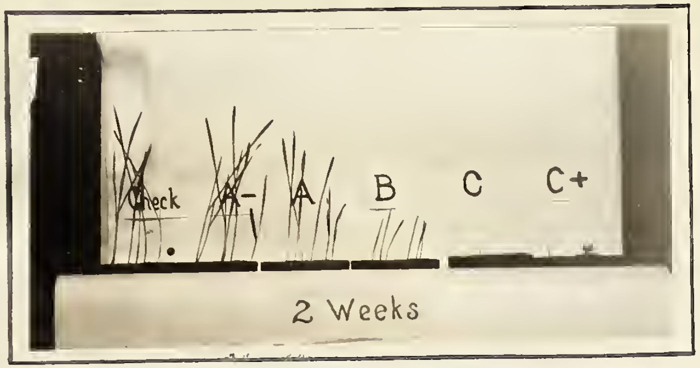
Total count or bacterial numbers in $Na_2Cr_2O_7$ treated fine sandy loam tumblers.

	At start	2 weeks	4 weeks	6 weeks	8 weeks
Conc. Ch.	15	13	44	36	35
" A-	15	21	47	20	26
" A	15	12	60	44	33 + 20#
" B	15	7 + 10#	1	111	30 + 78#
" C	15	3	8 + 70#	13 + 75#	8 + 111#
" C +	15	2	5 + 65#	10 + 60#	12 + 101#
Times 1,000,000 = numbers per gram of soil					

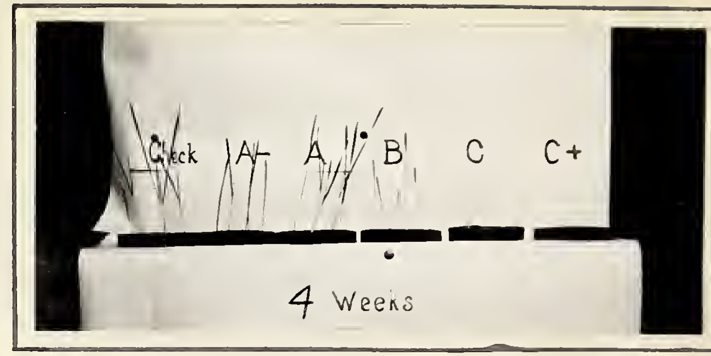
\# Very small colonies.

These determinations indicate that the numbers of fungi and bacteria in soil are greatly reduced or affected by the presence of $Na_2Cr_2O_7$.

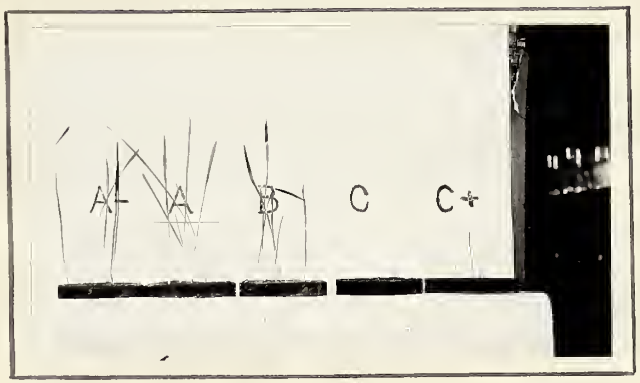
PLATE VI



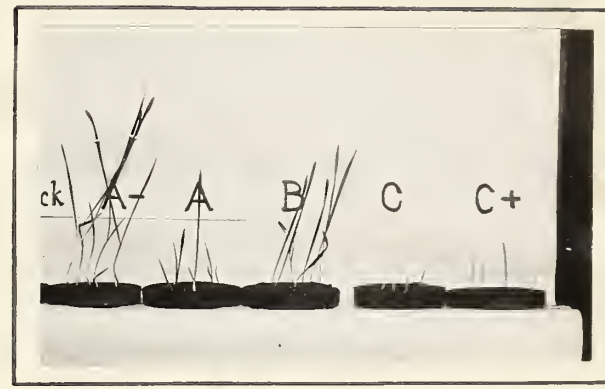
Seeds planted two weeks
after chemical was applied.



Seed planted four weeks after
chemical was applied.



Seed planted six weeks
after chemical was applied.



Seed planted eight weeks
after chemical was applied.

Growth of wheat seedlings on fine sandy loam after treatment with sodium di-chromate.

However, if these solutions are applied when the chromate has decomposed they may have a more beneficial effect.

One set of the check tumblers of fine sandy loam was treated with chrome alum. The amount of chromium added was equivalent to that in concentration "C" sodium di-chromate treatment. The soil receiving the alum supported a normal crop. This indicates that the chromium ion in the cation form is not toxic to wheat plants in the concentration used.

It was found that 3% alfalfa added, together with concentration "C" sodium di-chromate, to fine sandy loam rapidly neutralized the toxic effect of sodium di-chromate. The soil grew a normal crop when wheat was sown three weeks after treatment.

Experiments with sodium chlorate indicated that it was possible to leach the chlorate out of the soil beyond the limit of its toxic concentration. An analogous experiment was conducted using sodium di-chromate. Nine leaching tubes, each containing six hundred grams of soil were used. There were three tubes of each of the three types of soil. To two tubes of each soil concentration "C" $Na_2Cr_2O_7$ was added. Forty-eight hours were allowed to bring the soil and solution to equilibrium. It was intended to leach six inches of water through each tube, but as there was still a considerable amount of chromate in the leachings with that amount, a total of ten inches was collected. There was only a trace of chromate in the fraction caught from a further ten to twelve inch leaching. The results are given in Table XIII.

Table XIII

Leaching soil treated with sodium di-chromate.

Soil	Gms. of $Na_2Cr_2O_7$ added	Gms. of $Na_2Cr_2O_7$ retrieved	Av. gms. retrieved
Black 1	o.624	0.1001	
Black 2	0.624	0.1016	0.1008
Wooded 1	0.624	0.2146	
Wooded 2	0.624	0.2235	0.2190
F.S.L. 1	0.624	0.3608	
F.S.L. 2	0.624	0.3229	0.3419

The ten inches of water leached through contained 16.1% of the chromate that was added to the black soil; 35.1% of that added to the wooded grey soil; and 54.8% of that added to the fine sandy loam. This suggests that either the chromate is rapidly decomposed or it is adsorbed by the soil. If it is adsorbed by the soil then this might explain the toxic nature of treated fine sandy loam as shown by retarded plant growth when the water extract of this soil showed no test for chromates. If chromate is added to a soil and immediately extracted, from 92% to 95% is retrieved.

The soil from the leaching tubes was removed and planted with wheat. A normal crop grew on all soils. Or in other words no toxic effects appear to have remained in the soil. Consider-

ably more work will have to be done to prove the reason for the toxic action of the chromate on the soil.

WATER CULTURE EXPERIMENTS#

Experiments were conducted to determine the concentrations of certain chemical herbicides toxic to wheat plants in water or nutrient solution cultures. The effects of chemical herbicides upon plant roots may be modified by the presence of soil, and it was considered that the relative toxicity of different chemicals might be determined more definitely in a nutrient solution than in soils. There are fewer complicating factors in a nutrient solution, diffusion is rapid, and the solution can be standardized.

A standard plant culture solution, first recommended by Hoagland, was used in these experiments.

It was considered desirable first to test important perennial weed killers, since these are believed to have an important effect upon the roots of plants within the soil. The chemicals first tested were sodium chlorate and sodium di-chromate.

The relative toxicity of different chemicals in contact with sprouting seeds was determined by sprouting wheat seeds be-

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The water culture experiments were conducted by Dr. J.D. Newton, Department of Soils, University of Alberta.

tween blotting papers in Petri dishes. After moistening with the original solution, moisture was maintained by adding distilled water. Germination and growth of sprouts was observed four or five days after the seeds were moistened.

The experiment (See Table XIV) indicated that sodium di-chromate is much more toxic to germinating wheat than sodium chlorate, in equal concentration. A concentration of 1 gram sodium di-chromate per liter appeared to be more toxic than a concentration of 3 grams sodium chlorate per liter.

The relative toxicity of different chemicals in contact with plant roots, was determined by adding chemicals to nutrient solutions in which plants were growing. Duplicate liter, or quart jars of nutrient solution were used for each treatment and 5 (usually) wheat seedling plants were set in each jar. Chemical herbicides were added after plants had made a fair growth, and the effects, if any, on the appearance of the plants, were noted a few days later.

The experiment (See Table XV) indicated that, when placed in contact with plant roots, sodium di-chromate is toxic to the wheat plants in much lower concentration than sodium chlorate. For example, 0.1 gram of the di-chromate per liter appeared to be quite as toxic as 0.5 gram of the chlorate.

Barium Chlorate

A preliminary greenhouse experiment with barium chlorate was outlined. Duplicate crocks of fine sandy loam were treated with $Ba(ClO_3)_2$ using the concentrations given in Table I. The

Table XIV . Experiments to determine relative toxicity of different chemicals in contact with sprouting seeds.

In a liter	Solution	Wheat seeds set to sprout	Number germinated	Av. length of sprouts	Variation in length of sprouts
Sodium chlorate					
			Notes 4 days later		
0.0 g.	Dist. water	25	24	$1\frac{3}{4}$"	1/8"-$2\frac{1}{4}$"
0.0 g.	Nutr. sol.	25	24	2 "	$\frac{1}{2}$"-$2\frac{3}{4}$"
1.0 g.	Dist. water	25	25	$\frac{3}{4}$"	1/8"-1,1/8"
1.0 g.	Nutr. sol.	25	23	$1\frac{1}{4}$"	1/8"-$1\frac{3}{4}$"
3.0 g.	Dist. water	25	25	5/8"	1/8"-1"
3.0 g.	Nutr. sol.	25	23	5/8"	1/8"-1 1/8"
Sod. Dichromate					
			Notes 5 days later		
0.0 g.	Dist. water	25	24	$1\frac{1}{2}$"	$\frac{1}{2}$"-$2\frac{1}{4}$"
0.0 g.	Nutr. sol.	25	24	2 "	$\frac{1}{2}$"-$2\frac{3}{4}$"
1.0 g.	Dist. water	25	24	$\frac{1}{4}$"	1/16"-$\frac{1}{2}$"
1.0 g.	Nutr. sol.	25	20	$\frac{1}{4}$"	1/16"-$\frac{1}{2}$"
3.0 g.	Dist. water	25	11	1/8"	1/16"-$\frac{1}{4}$"
3.0 g.	Nutr. sol.	25	7	1/8"	1/16"-$\frac{1}{4}$"

Wheat seeds were sprouted between blotting papers in Petri dishes. After moistening with the original solution, moisture was maintained by adding distilled water.

The experiments indicate that sodium dichromate is much more toxic to germinating wheat than sodium chlorate, in equal concentration. A concentration of 1 g. sodium dichromate per liter appears to be more toxic than a concentration of 3 g. sodium chlorate per liter.

Table XV. Experiments to determine relative toxicity of different chemicals in nutrient solution cultures.

Sodium chlorate grams per liter	Age of plants on adding chemicals	Notes 14 days later	Sodium dichromate grams per liter	Age of plants on adding chemicals	notes 13 days later	Sodium chlorate grams per liter	Age of plants on adding chemicals	Notes 10 days later
0.0 g.	18 days	checks healthy	0.0 g.	15 days	checks healthy	0.0 g.	32 days	checks healthy
0.1 g.	18 days	Like checks	0.1 g.	15 days	much wilted	0.1 g.	32 days	like checks
			0.3 g.	15 days	practically dead	0.3 g.	32 days	slightly wilted
0.5 g.	18 days	partly wilted	0.5 g.	15 days	practically dead	0.5 g.	32 days	much wilted
1.0 g.	18 days	much wilted	1.0 g.	15 days	practically dead	1.0 g.	32 days	pract. dead
3.0 g.	18 days	much wilted						

Duplicate liter (or quart) jars were used for each treatment, and 5 (usually) wheat seedling plants were set in each jar. Chemicals were added after plants had made a fair growth.

The experiments indicate that, when placed in contact with the roots, sodium di-chromate is toxic to the wheat plants in much lower concentration than sodium chlorate. 0.1 g. sodium di-chromate per liter appears to be quite as toxic as 0.5 g. sodium chlorate.

amounts used were equivalent in oxidizing values to the concentrations of $NaClO_3$ used throughout this work.

Wheat sown six months after the application of the barium chlorate showed that it was at least as toxic as sodium chlorate.

SUMMARY

(1) Soil experiments with several chemical herbicides were conducted in the field, in the greenhouse and in a controlled chamber. Generally three typical Alberta soils were used for pot culture work.

(2) The special method adopted for the determination of small amounts of chlorates in soils and for the determination of nitrates in the presence of chlorates are outlined, and all methods used are stated in the body of the thesis.

(3) Sulphuric acid in quantities used for control of annual weeds appeared to have no residual lethal effect on the Alberta Soils studied.

(4) Copper sulphate in quantities used for the control of annual weeds appeared to have no lethal after effect on these soils. Nitrification was but slightly affected following its application. It did increase the percentage

of grain to straw when applied to the growing crop, and an appreciable decrease in yield due to the $CuSO_4$ might have been shown if the check plots had not lodged.

(5) Much of the $NaClO_3$ applied will remain undecomposed in moist soils under greenhouse conditions for at least eighteen months.

(6) $NaClO_3$ retained its toxicity in the Edmonton field for at least one year.

(7) $NaClO_3$ will move with the soil water and in a period of average or high rainfall will concentrate in the subsoil. That is , leaching plays an important role in its distribution and toxicity.

(8) With the rainfall for Edmonton, 1931, (approximately 17 inches from May to September inclusive) the surface foot was practically freed of the toxic effect of $NaClO_3$. This suggests that shallow-rooted crops might sometimes be grown more successfully than deep-rooted crops following its application.

(9) Sodium chlorate, in the quantities used in these experiments, did not prevent, or greatly affect nitrification. Nitrification proceeded rapidly in the presence of chlorate when nitrogenous organic matter was added to the soil.

(10) In controlled laboratory experiments $NaClO_3$ had some depressing effect on the numbers of soil microorganisms.

(11) Twenty-five tons of manure, one ton sulphur or one ton sulphuric acid per acre in pot cultures did not aid decomposition of $NaClO_3$ in a marked degree.

(12) Approximately 10 per cent organic matter in the form of alfalfa in pot experiments promoted rapid decomposition of $NaClO_3$. This suggests that under favorable conditions, the toxic effect of $NaClO_3$ may be removed from the surface soil by incorporating a large application of readily decomposable organic matter with the surface soil.

(13) $NaClO_3$ does not appear to leave any toxic oxidation products of its decomposition.

(14) Sodium di-chromate in comparison with sodium chlorate appears to decompose in the soil very rapidly. Edmonton black soil pot cultures supported a normal growth of wheat in six months.

(15) In controlled laboratory experiments $Na_2Cr_2O_7$ had a depressing effect on the numbers of soil microorganisms. It also had a decidedly depressing effect on soil nitrification in pot cultures.

(16) The addition of 75 p.p.m. of nitrate nitrogen to fine sandy loam three weeks after the application of $Na_2Cr_2O_7$ failed to neutralize the toxic effect of the chromate.

(17) Fine sandy loam containing 3% ground alfalfa supported a normal crop three weeks after the application of Conc.

"C" sodium di-chromate.

(18) Leaching ten inches of water through the soil 48 hours after the application of $Na_2Cr_2O_7$ recovered only a small percentage of the chromate added. Wheat sown immediately after leaching, however, grew normally.

(19) Water or nutrient solution culture experiments indicate that when placed in contact with germinating wheat seeds, and in contact with growing wheat plant roots, sodium di-chromate is much more toxic to the wheat than sodium chlorate in equal concentration.

(20) A preliminary experiment indicates that the toxicity of barium chlorate is similar to that of sodium chlorate.

(Note: In testing the residual effect on crop growth, wheat was the only plant used).

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